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Remote characterization of littoral dynamics in support of expeditionary warfare

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Abstract – Over the last decade there has been an increasing interest in conducting expeditionary warfare operations in very shallow water and surf zone regions, with depths typically less than 10 m. The consequences of inadequately estimating littoral environmental conditions in these regions can be substantial to military system performance. Interestingly, the spatial diversity and dynamic nature of littoral processes that have a direct impact on expeditionary warfare operations are often limited to a particular location (on the order of 100s of meters) and/or a relatively short time interval (on the order of hours to days). Given this complexity, traditional solutions for environmental characterization involving historical databases or climatologies are inadequate. In contrast, an adaptive solution for nowcasting littoral conditions in high resolution is required to provide a tactical, organic, reconnaissance capability in support of amphibious operations and mine countermeasures. Such a solution known as the Littoral Environmental Nowcasting System (LENS) and its potential applications are described herein.

Introduction

Environmental processes in littoral regions occur over a variety of temporal and spatial scales. Examples include tides, waves, currents, and bathymetric changes via sediment transport. These processes are dynamic such that environmental characterizations have a limited “shelf life”, typically less than a few days, in that conditions can change quickly. As examples, breaker wave heights clearly are altered by the variation in depth over a tidal cycle and changes in beach profiles of more than a meter have been observed over time spans as short as a few hours. Also these processes are site specific in that closely located areas may show similarities, but often have important differences such as rip currents or particularly high wave energy regions.

These dynamic environmental conditions can have a direct impact on systems developed for use in expeditionary warfare, particularly with respect to mine countermeasures operations. For example, planned use of autonomous systems including Unmanned Underwater Vehicles (UUV) and “crawler” deployments for mine detection will be dependent upon wave and current conditions to avoid being either damaged or transported away from the intended survey area. Also choosing efficient survey routes relative to existing bathymetry and/or surf zone locations can reduce survey time. Mine burial is highly dependent upon sediment type and bottom current magnitudes. Operations occurring during amphibious landings including lane marking and precision

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navigation can be impacted by nearshore wave and current conditions. Also, rapid environmental assessment is important to prepare the VSW/SZ battlespace for amphibious operations/littoral penetration. In essence, many elements of Ship To Objective Maneuver (STOM) (e.g. breaching, sweep, precision neutralization, and follow-on clearance) will benefit from knowledge of littoral environmental conditions. Precise knowledge of littoral environment allows tactical decisions resulting in:

- Fewer assets required
- Optimal deployment of assets (vehicles & timing)
- Reduced time to secure/clear op area
- Higher confidence in force protection
- Safest methods/routes to accomplish objectives

This capability is particularly important in the very shallow water, surf, beach, craft landing, and beach exit zones (VSW / SZ / BZ / CLZ / BEZ).

Unfortunately, existing environmental information in forward areas is usually sparse, sometimes outdated, and often inaccurate making assessment of potential impacts on expeditionary warfare operations challenging. Traditional survey operations typically have a long turn-around time. Additionally, relevant environmental information is difficult to acquire in hostile/denied areas using in-site measurements or covert reconnaissance. In this publication, we present a demonstrated capability for providing such environmental information as part of a tactical operation. This capability results from the fusion of advanced numerical modeling with real-time information derived from imagery obtained by Unmanned Aerial Vehicles (UAVs). Basically, we have adapted an existing numerical circulation model for simulating hydrodynamic and morphological processes in the littoral environment for use with remotely-sensed nearshore characterizations. This approach, known as LENS for Littoral Environmental Nowcasting System, has been demonstrated at four scientific experiments or military exercises and shows much promise for adaptation to fleet use.

Littoral Environmental Nowcasting System (LENS)

The objective of the Littoral Environmental Nowcasting System program is to develop and demonstrate technology and techniques that will enable a rapid and tactical reconnaissance capability using Unmanned Aerial Vehicle (UAV) imagery for characterizing littoral processes from very shallow water into the beach exit zone. As previously mentioned, this capability is critical to several aspects of expeditionary warfare including autonomous vehicle operations involved in Mine Counter Measures (MCM), locating mines / minefields / obstacles, and efficiently conducting amphibious landings. There is a clear operational need for such characterization in that few present countermeasure systems are designed to operate in the SZ region. In planning this solution, we decided to collect data at high density as part of ongoing operations. Requirements include being minimally intrusive such that there is little interference with the primary mission, no alterations resulting in a compromise of platform safety and the capability should be largely automated to preclude the need for specially trained operators.

System Description

The LENS program is motivated by the fact that in-stride neutralization of mines and prediction of mine burial in VSW/SZ regions requires up-to-date knowledge of environmental conditions in these dynamic areas. Since wave and bathymetric conditions in these areas can vary dramatically over time periods as short as a few hours, a coupled remote sensing and numerical forecasting approach is required. Based upon recent advances in imaging sensors, signal processing, and numerical modeling, LENS is a software system that uses remotely-acquired, temporally and spatially variant information from electro-optical sensors to provide high resolution nowcasts for VSW and SZ regions. Estimates of breaker height, dominant wave period, wave direction, shoreline location, bar location, surf zone width, and the number of waves in the surf zone are provided, in addition to standard meteorological information, and geo-referenced digital imagery. Bathymetry and littoral currents can also be determined, as can imagery products relating to vessel tracking and submerged object detection.

The system (diagrammed in Figure 1) primarily consists of an electro-optical (EO) motion imagery sensor that provides time sequential ("video-like") imagery. Visible band color imagery has been typically used although these capabilities are applicable to infrared, multispectral, or even hyperspectral sensors. A fundamental requirement of the data collection is that the imagery be associated with additional metadata to allow photogrammetric rectification of pixel information to world coordinates such as UTM. This metadata is typically provided by external hardware that measures camera position, pitch, roll and yaw, but these angles can also be determined using stereometric processing of control points on the ground using methods established for application to field sensors. Littoral characterization algorithms are then applied to the imagery data streams to determine the boundary and forcing conditions (namely bathymetry and ocean wave characteristics) that can be used to drive numerical hydrodynamic and circulation models.

Littoral Environmental Nowcasting System (LENS)

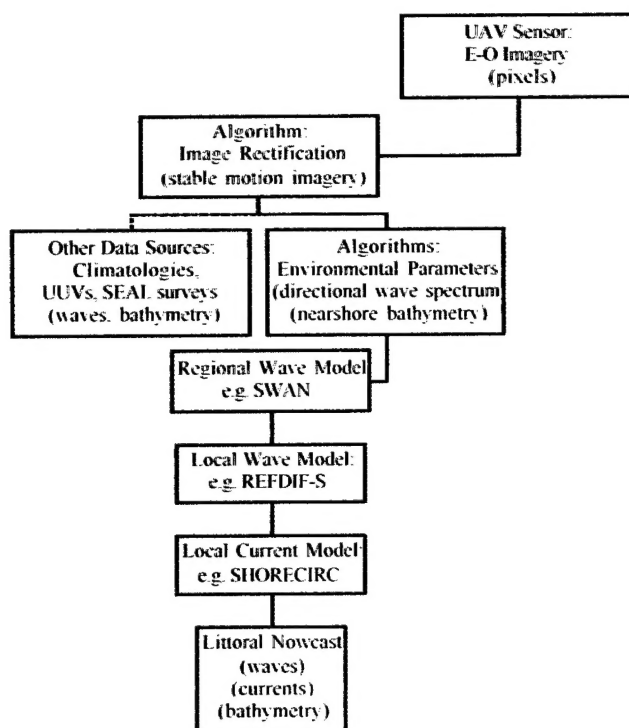


Figure 1 – Schematic showing LENS coupled systems approach to littoral nowcasting.

The littoral characterization algorithms were developed using E-O sensors deployed from fixed platforms, such as in towers, lighthouses, or on hilltops. These installations offered the advantages of long-term sampling with minimal difficulties relating to system size, power or data storage. Additionally, the viewing geometry generally remains fixed allowing repeated pixel based analyses to be highly automated. Subsequently, the algorithms were tested on imagery collected from airborne platforms, such as UAVs, which typically has a much higher viewing angle resulting in a more consistent pixel footprint through the coverage area. One advantage of the UAV approach is that imagery can be rapidly collected at a number of spatial locations, and is generally more suitable for covert military operations. One disadvantage of airborne imagery is that the geometric transformation between image and ground coordinates has to be recalculated for each image frame, but that process has been automated. Collections using airborne vehicles are generally preferable to space-based platforms given the often lower pixel resolution and shorter temporal dwell of the satellites.

Numerical models of nearshore processes (waves, currents) have reached an advanced stage of sophistication and accuracy to make their use as prediction tools tenable. For the simulation of nearshore wave and current fields, typical input includes bathymetry (at a resolution sufficient to include major features such as bars) and offshore wave conditions (spectral parameters such as peak period, height and direction or full directional spectra). Generally, a coupled wave and hydrodynamic model approach is used, with the wave field over a larger region calculated from the initial condition and the resulting forcing

information provided to the circulation model which operates over a smaller region. The bathymetric resolution requirements are usually similar between the two models. An example nearshore characterization product for La Jolla, CA is shown in Figure 2.

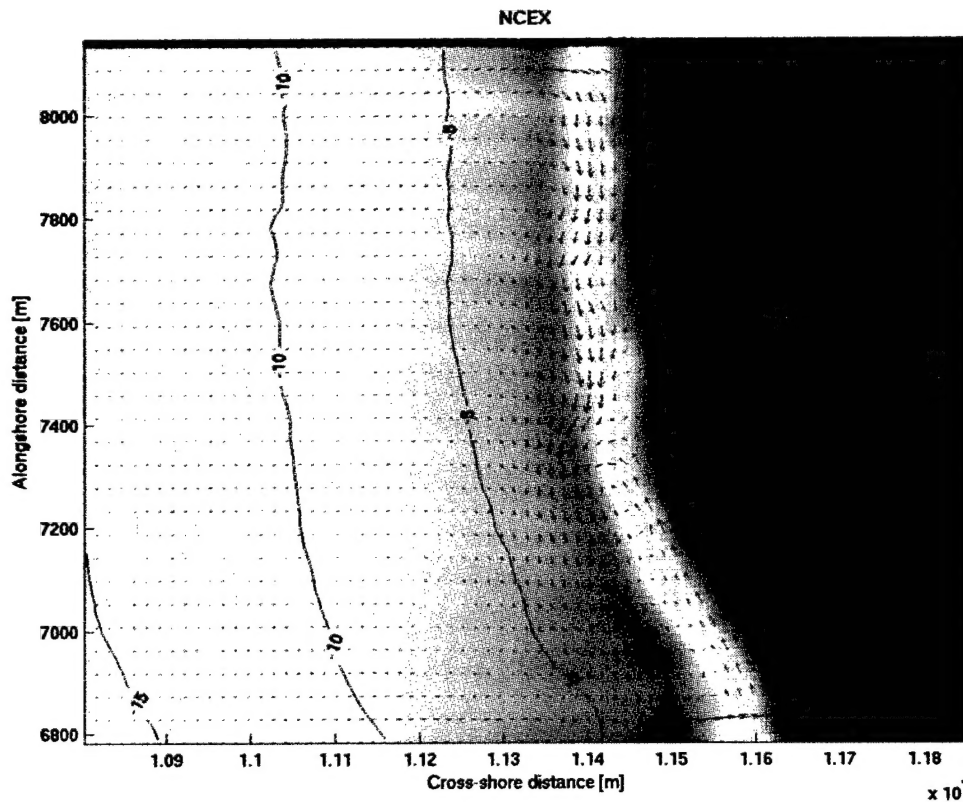


Figure 2 – Example nowcast product showing wave height and current patterns for a 1.2 x 1.2 km nearshore region. Depth contours are in meters.

An important part of the technical approach has been to validate the LENS prototype as part of scientific experiments and military exercises using imagery from TUAV and UAV surrogates. Validation of these capabilities using in-situ measurements such as hydrographic surveys and directional wave buoys has shown excellent agreement at a variety of locations (see Figure 3).

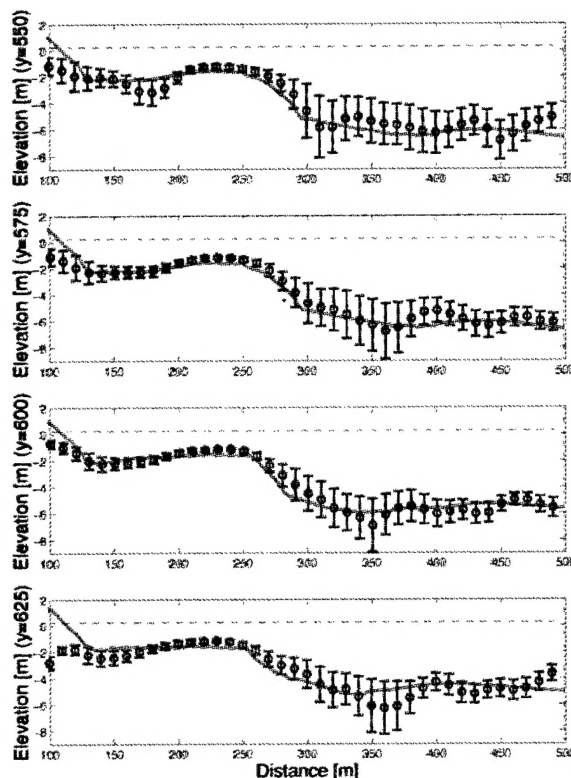


Figure 3 – Remotely sensed estimates of bathymetric profiles (blue) at 4 alongshore locations compared to surveyed profiles (magenta) obtained at Duck, NC.

Operational Concept

Prior to an amphibious assault, real-time reconnaissance including detecting and locating mines, minefields, and obstacles often occurs using autonomous vehicles that will be impacted by adverse oceanographic conditions such as breaking waves, strong currents, or abrupt changes in bathymetry. For example, remotely operated, underwater, mine hunting vehicles cannot easily transit against a littoral current exceeding their maximum travel speed. Similarly, vehicles entering the surf zone region may be stranded or rendered inoperable. In addition, the success of follow-on mine clearing operations will in many ways depend upon similar knowledge of the littoral environmental conditions.

The LENS operational concept therefore is to process, in near real-time, stabilized motion imagery obtained from an organic UAV and telemetered to the ground (or recorded on-board). The major hardware requirements are that sufficient navigational data (such as platform location and sensor heading) are provided to allow for image co-registration and geo-rectification. Analysis of the imagery time series provides the boundary and forcing conditions (such as bathymetry and wave spectra) necessary to initialize hydrodynamic and morphodynamic models to allow estimation of littoral conditions. In addition, these estimates can be updated periodically to provide continued forecasting abilities over a 2 – 3 day period. The final output can be used to design UUV and UAV deployment strategies, isolate optimal littoral penetration points, and help the commander determine

the most successful mix of breaching and/or clearing approaches. The various imagery products available from the LENS analysis are also useful in identifying mine-like objects and for surveillance of moving vehicles (Figure 4). Many of these developments are relevant to related technology planned for tactical UAV employments including multispectral/hyperspectral (UV-VIS-NIR-SWIR-LWIR) cameras with coupled advanced laser illuminators.

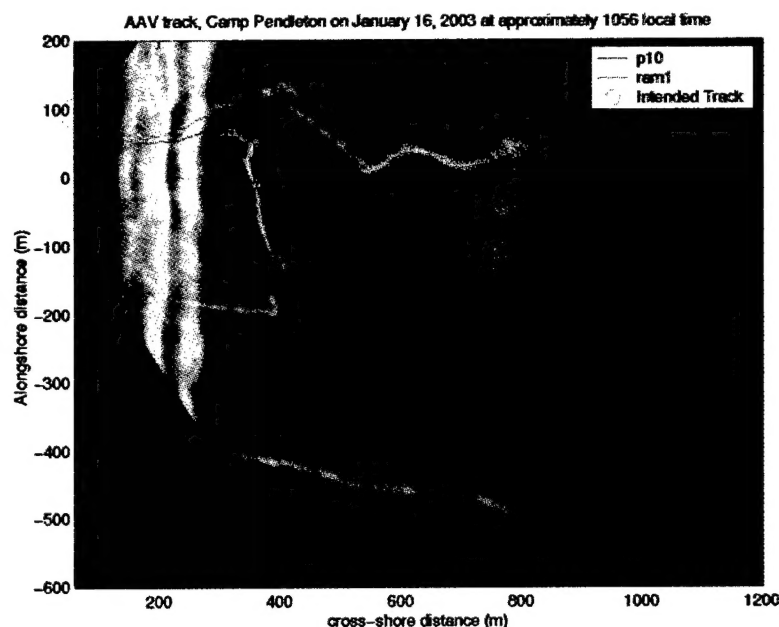


Figure 4 – Estimates of AAV tracks obtained from a variance exposure using motion imagery compared to sampled GPS coordinates (magenta and blue lines).

Discussion

Examples of how the environment can impact expeditionary warfare operations are listed in Table 1. LENS can be used to address many of these missions.

Table 1

<i>Environmental Products:</i>	<i>Impacted Operations:</i>
Bathymetry / Sea State	Amphibious landings / MCM
Littoral Dynamics (Currents / Surf)	UUV maneuverability / EOD divers
Physical Processes (Density / Temp)	Marine mammal systems
Seafloor and Terrain Characteristics	Mine detection / Trafficability
Targeting / MLOs / Hazards	Neutralization / Obstacle avoidance
Beach / Riverine Characteristics	Special operations

An important concept relating to littoral characterization is that the size of necessary coverage region decreases while required resolution of conditions increases as time towards mission progresses. For example, planning decisions made several days prior to an assault involving generalized wave conditions (such an expected maximum wave

height) require only coarse estimates (e.g. grid spacings of 100s of meters) of the regional bathymetric surface. However these forecasts need to be made over a sizeable spatial domain (perhaps 500 km²) to gauge environmental variability associated with multiple potential littoral penetration points. In contrast, determination of survey routes for MCM mission regions of 50 km² size necessitates knowledge of bathymetric variations to within 10s of meters. Furthermore, accurate estimation of surf zone conditions pertaining to a specific 50-m wide assault lane could involve having bathymetry measurements spaced by as little as a few meters.

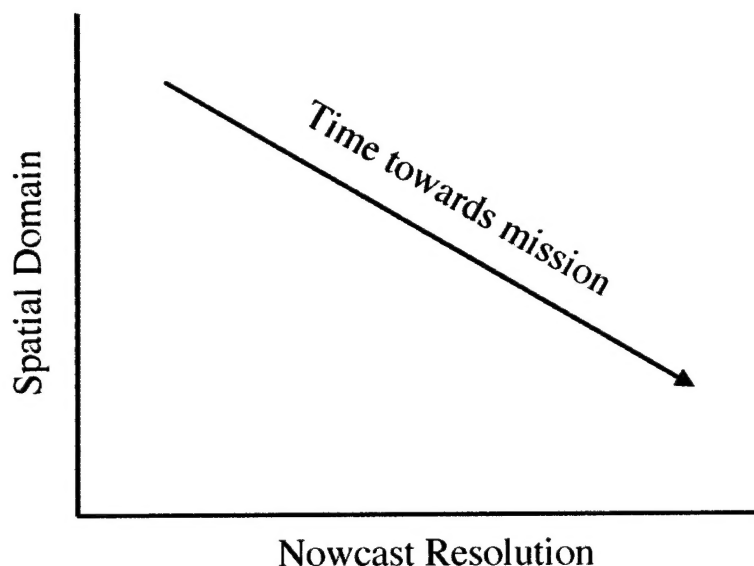


Figure 5 – Schematic showing relationship between spatial coverage and resolution requirements as time towards mission progresses.

Although complete characterization over these required scales is a formidable challenge, this concept has significant implications towards MCM mission planning and asset deployment. Primarily, these requirements are achievable if a nested and sequential approach to littoral characterization is pursued. Ideally, low density but regional bathymetric measurements provided by historic databases such as DBDBV are sufficient to define the bottom boundary used by numerical models such as WaveWatch III to estimate large coverage wave variations used during planning stages. As likely littoral penetration areas are chosen, national and theater capabilities can be tasked to more accurately estimate bathymetry within more constrained regions. These measurements can then be used to drive higher resolution numerical simulations (such as SWAN) that aide in the optimal deployment of tactical assets such as UUVs and UAVs. The sensors on these vehicles provide even higher resolution bathymetry estimates, along with allowing even greater fidelity in the following numerical nowcast such as Delft3D. By the time of the assault, a high-resolution depiction of the environmental conditions within a reasonably small, but especially relevant littoral region is available.

There is at least one significant impediment to successful implementation of this scheme. Primarily, as the distance to the “pointy end of the spear”, where the most tactically relevant environmental information is required, increases, the on-scene expertise

available to process data and perform numerical simulations decreases. Quite simply, the warfighter is involved in a number of other activities more pressing than conducting a littoral nowcast. However, since we believe that a great portion of the mission success will depend on littoral environmental conditions, we propose an advanced solution to this delima.

Summary

The LENS operational concept therefore is to process, in near real-time, stabilized motion imagery obtained from an organic UAV and telemetered to the ground (or recorded on-board). The major hardware requirements are that sufficient navigational data (such as platform location and sensor heading) are provided to allow for image co-registration and geo-rectification. Analysis of the imagery time series provides the boundary and forcing conditions (such as bathymetry and wave spectra) necessary to initialize hydrodynamic and morphodynamic models to allow estimation of littoral conditions. In addition, these estimates can be updated periodically to provide continued forecasting abilities over a 2 – 3 day period. The final output can be used to design UUV and UAV deployment strategies, isolate optimal littoral penetration points, and help the commander determine the most successful mix of breaching and/or clearing approaches.